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INTERNAL MOTION IN THE SPIRAL NEBULA MESSIER 33

PRELIMINARY RESULTS

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One of the most interesting questions in astronomy concerns the relation of the spiral nebulae to the galactic system. Are they or are they not separate stellar systems comparable with our own? Especially during the last few years have many arguments been advanced both for and against. Real internal motions of the order indicated by the measures on Messier 101, communicated to these Proceedings in 1916,[1] would raise a strong objection to the "island-universe" hypothesis. If comparable with our own system, spiral nebulae would be so distant that no ordinary velocities of their constituent parts would yield measurable displacements in the short interval of a few years.

The measures on Messier 101 were, however, based principally on two plates taken by Mr. Ritchey at the 25-foot focus of the 60-inch reflector with an interval of only five years, and required confirmation before a general acceptance of the results could be expected. This was afforded in part by measures of three photographs of the same object taken at the Lick Observatory, which were kindly loaned by Director Campbell. Measures on Messier 81 also pointed in the same direction; while Lampland[2] found analogous motions for Messier 51 in 1916, and Kostinsky[3] in 1917.

Meanwhile another five years has elapsed, which would have doubled the interval for the 60-inch reflector photographs of Messier 101; but, unfortunately, bad weather during the spring made it impossible to obtain a satisfactory plate. In August, 1920, however, Mr. Duncan secured a fairly good photograph of another spiral, Messier 33, for which an excellent plate, taken by Mr. Ritchey in 1910, was also available. Messier 33 is, moreover, better adapted for such measures than Messier 101, on account of its numerous condensations and their close approach to star-

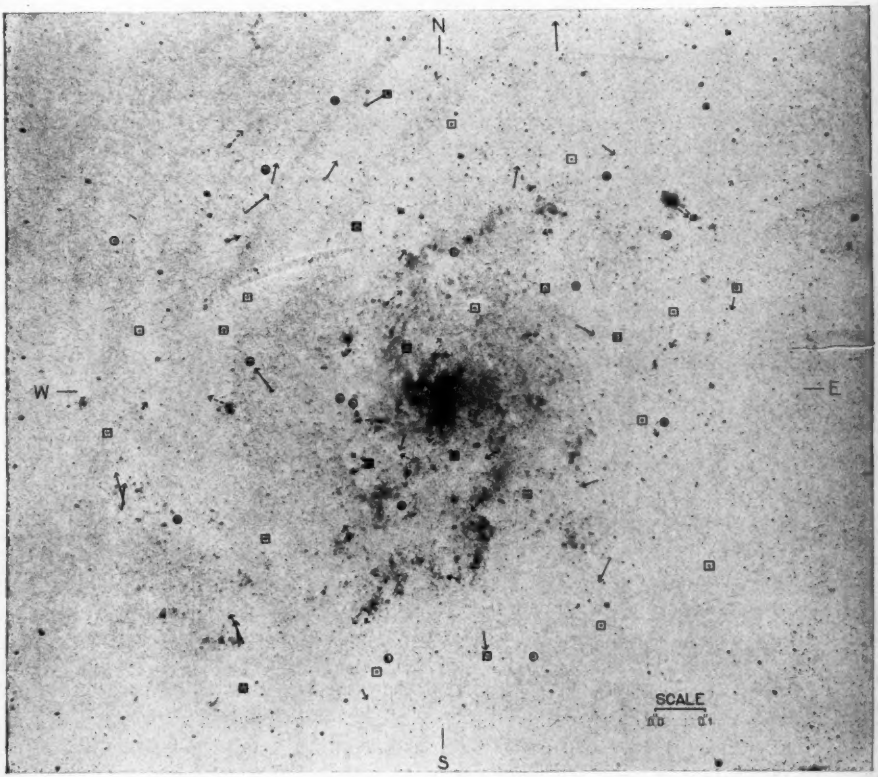
like appearance. For this same object two plates of short exposure, taken at the 80-foot focus of the 60-inch reflector in 1915 and 1920, were also available.

Both these pairs of plates have been measured with the monocular arrangement of the Zeiss stereocomparator. It has been shown that with temperature properly controlled this instrument is admirably adapted to such measures, because it allows the bisection in quick succession of corresponding points on the two photographs; the possibility of not bisecting a nebulous and asymmetrical point in the same way on both plates is thereby greatly reduced, if not wholly avoided. A note on the unreliability of the stereocomparator for accurate measures has recently been published by Kreiken;[4] but, as I have pointed out several times it is only necessary to keep the temperature of the room constant in order to secure good results with the Zeiss instrument. In our case the change in temperature during a series of measures can be kept within a few tenths of a degree. The influence of this variation is extremely small; but, as an extra precaution, we have adopted the plan of measuring the n points, first in the order $1 \ldots\ldots n$, then in the order $n \ldots\ldots 1$. In this way practically all temperature effect can be eliminated, and it is easy to prove that the measures of the present series, which are of moderate length, cannot be affected by more than 10 or 12 per cent. For a series of several hundred points, whose measurement would take several days, the conditions are not so favorable, and in the present case it was thought best to await the completion of a new stereocomparator, now under construction in the instrument shop of the Observatory, in which the principal sources of trouble have been avoided, before undertaking the complete measurement of the plates.

For a preliminary discussion, 24 comparison stars and 23 nebulous points were selected on the plates taken at the 25-foot focus. When the measures had been finished, Mr. Seares was kind enough to call my attention to some photographs of Messier 33 taken by him with and without color-screens. A few years ago Seares found that the outer points of spiral nebulae are decidedly blue in color. A rough comparison of his plates showed that I had been fortunate in the choice of both comparison stars and nebular points. Of the first only three are blue, while of the latter all but two are decidedly blue; these two points have been omitted in the following discussion, since they may not belong to the nebula.

On the plates taken by me at the 80-foot focus all measurable points, a total of 89, were used. After the measures were finished I selected, with the help of the photographs taken by Mr. Ritchey and by Mr. Seares, 23 objects as comparison stars; these are all starlike in appearance and reddish in color. Ten points which are either very bright or very faint or for which the measures are uncertain were excluded. Of the remaining points, 22, including the centre, almost certainly belong to the nebula,

as they seem to be involved in the nebular knots and, with the exception of the centre, are decidedly blue. Fourteen points are probably nebular, being seemingly involved in nebulosity but not decidedly blue, or blue but not so clearly involved in the nebula. For 20 points it is quite uncertain whether or not they form part of the nebula.



Internal motions in the spiral nebula Messier 33. The dotted- and full-line arrows show the motions of points in the nebula derived from each of two pairs of photographs. The comparison stars are enclosed in small squares and circles.

For each set of plates the proper motions μ_α and μ_δ were derived for all the points measured with respect to the 24 and 23 comparison stars used. These motions for the points belonging to the nebula are presumably due partly to a translation of the nebula as a whole, and partly to internal motion. By a method analogous to that followed for Messier 101 the motion of translation of the nebula was found to be

$$\mu_\alpha = -0''.007, \ \mu_\delta = -0''.002.$$

The results found by subtracting these values from the motions of the nebular points are assumed to represent internal motions. In plate I those for the 30 points of the 25-foot focus plates are indicated by arrows with full lines and for the 22 very probable nebular points measured on the 80-foot focus plates by arrows with broken lines; the comparison stars of the first pair are enclosed in small squares, those of the second pair in circles.

A first inspection of the plate leaves us again in doubt as to whether we are dealing with a rotation of the nebula as a whole or with a motion along the arms of the spiral; upon further examination the latter motion seems to be more clearly indicated.

Resolving the motions into components perpendicular to and along the radius, we find the following results:

	25-FOOT FOCUS	80-FOOT FOCUS
Right-handed	23 or 77%	17 or 81%
Left-handed	7 or 23%	4 or 19%
Outward	18 or 60%	15 or 71%
Inward	12 or 40%	6 or 29%
Mean tangential motion	+0".020	+0".014
Mean radial motion	+0".006	+0".012

+ means right-handed and outward

Classifying the points according as they have a component of motion outward or inward along the arms of the spiral, we have the following results:

	25-FOOT FOCUS	80-FOOT FOCUS
Motion outward	28 or 93%	18 or 86%
Motion inward	2 or 7%	3 or 14%
Mean outward motion	0".024	0".021

Before discussing the possibility of an increase or decrease of motion with distance from the centre it will be necessary to measure a large number of additional points in the nebula, which is deferred for the present. The principal conclusion to be drawn from the present material is that here again we find motions analogous to those occurring in Messier 101, 81 and 51. In general they seem to be outward along the arms of the spiral.

In 1916 Pease published values for the radial velocity of the centre of Messier 33 and for the bright knot 10′ *nf* the nucleus. The two values differ by about 200 km./sec. Taking into account the probable inclination of the nebula with respect to the tangential plane, we can gain some

idea of the order of the parallax of the nebula by comparing Pease's results with those obtained from the present investigation; the corresponding parallax is about 0".0005. The diameter of the nebula would be about 100 light-years and the individual points of the nebula would have absolute magnitudes of +1 and fainter.

If on the other hand we suppose the dimensions of Messier 33 to be comparable with those of the galactic system, its distance would be several million light-years; the motions indicated by the photographs would then represent velocities of the order of 150,000 to 300,000 km./sec., which, obviously, are extremely improbable. The internal motions in the spirals seem now to be well founded, and if time justifies this belief, they will accordingly afford a most important argument against the view that these nebulae are systems comparable with our galaxy.

[1] van Maanen, A., *Mt. Wilson Contr.*, No. 118, 1916; *Astrophys. J., Chicago, Ill.*, **44**, 1916 (210–228).

[2] *Amer. Astron. Soc. Publ.*, **3**, 1918 (206–207).

[3] *Monthly Notices, Lond.*, **77**, 1917 (233–234).

[4] *Observatory, Lond.*, **43**, 1920 (255–260).

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*THE ATTACHMENT OF ELECTRONS TO NEUTRAL MOLECULES IN AIR**

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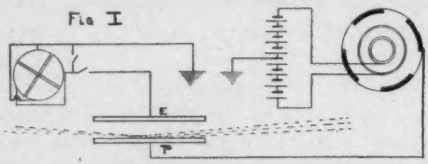
Communicated by R. A. Millikan, December 4, 1920

It is well known that the process of ionization in gases consists of the detachment of an electron from the molecules or atoms ionized. It has further been proved that in air at atmospheric pressure the carriers of negative electricity are neutral molecules[5,6] of the gas carrying an additional electron. These are called the normal ions. Now it is of interest to determine in what manner the electron liberated by the ionizing process attaches itself to a molecule to form an ion. For it is possible that an understanding of this process may help us to gain a picture of the surfaces of the molecules.

In air at atmospheric pressure the normal negative ions move with a velocity of 2 cm./sec. in unit electric field while the electrons have a mobility of about 200 cm./sec.[3,7] under the same conditions. Such a marked difference in the two types of carriers accordingly furnishes us an excellent means of investigating the above question as the ensuing analysis will show.

Let us assume that the electrons liberated from the plate P, figure 1, by ultraviolet light unite with gas molecules on their first impacts to form ions. Now let a second plate, E, connected to an electrometer be placed

parallel to P and d cm. above it. On applying an alternating potential difference of half period T between P and E the ions starting from P will alternately be driven from, and drawn back to P, for periods of T seconds. If u is the velocity of the ion in unit field, then for given values of T and d there will be no current to E until V reaches a value V_0 such



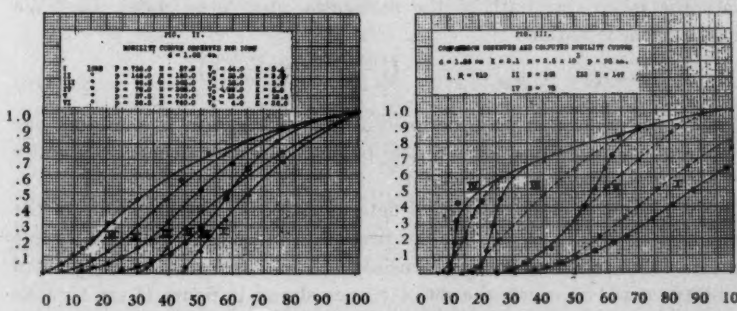
that $uTV_0/d = d$. At V_0 then a current to E will become manifest which will increase with increasing V to a saturation value. On plotting the current i as ordinate against the voltage V as abscissa we will get a curve of the type of curve I, figure II. Such a curve will be termed a mobility curve for if the value of the intercept V_0 of such an experimental curve be substituted in the equation

$$u = d^2/V_0T \qquad (1)$$

the mobility u of the carrier is at once obtained if d and T are known. When the pressures are reduced the curves remain the same but the value of the mobility u of the ion is found to increase inversely as the pressure. In other words $up/760 = K$, where K, the *mobility constant* of the ions, is independent of pressure.

Now let us assume with J. J. Thomson[1] that an electron does not attach to form an ion on its first encounter with a gas molecule, but that the attachment is a chance phenomenon occurring on the average in one out of n impacts with molecules. Let us further assume that for air n is large, say, about 250,000. Under ordinary conditions the velocity of thermal agitation of the electron is great compared with its velocity acquired in the electric field. The electron, therefore, covers a zigzag path drifting slowly all the while in the direction of the electric field. Consequently while making the 250,000 impacts necessary for attachment the majority of the electrons will move a distance, A, in the field, which may be estimated. Since A is covered by the electron in 1/100 of the time that an ion would take, one may practically assume that the majority of the ions start at a point distant A cm from P instead of from P. For appreciable values of A the values of V required to drive the majority of the carriers to E may become notably lower than they are for ions starting at P. The values of u and hence of K obtained from experiments where A becomes significant will then be high. In air at atmospheric pressure the time taken for an electron to make 250,000 impacts is about 1.2×10^{-6} sec. In a field of 40 volts with $d = 15$ mm. the electron would cover a distance of 6.3×10^{-2} mm. towards E in this time. This small value of

the distance A covered as an electron would produce no measurable effect on V_o and the values of K would be normal. Now let the pressure be reduced to 152 mm. The mobility of the electrons will be increased five-fold. Furthermore as the density of the gas is reduced to one-fifth the electrons will take five times as long to make the 250,000 impacts required to attach. The distance A will, therefore, become 1.5 mm. which is an appreciable fraction of the 15.0 mm. between the plates. The intercept V_o as determined from the portion of the curve corresponding to the majority of the carriers will, therefore, be but 0.9 of the V_o required for ions, and the value of K will be about 10% higher than for normal ions. In other words assuming the Thomson mode of attachment the mobility constant of the ions will appear to increase with decreasing pressures below about 152 mm.[2] Since the number of impacts required to form an attachment is a *chance* phenomenon there will be an appreciable number of ions reaching E that have traversed distances greater than A before attaching. These will reach E at values of V_o below those for the majority of carriers. As a result the otherwise sharp intercepts of mobility curves with the voltage axis observed for *ions* will be masked by asymptotic feet of exponential form rising at values of V well below the V_o required for the majority of the ions. These will become rapidly more pronounced



as the pressures decrease. Such curves are seen in the experimental curves II, III, IV, V and VI, figure II, obtained in air under conditions indicated in the legend. To estimate the *hybrid* mobilities of such carriers the asymptotic feet must naturally be ignored, as has been done by previous observers.[2§]

With the method of analysis outlined above it would be possible to pursue the evolution of the mobility curves as a function of p and T in a qualitative manner indefinitely. Fortunately a much simpler and more accurate study of the theory is made possible by the application of the mathematical analysis of Thomson. On the basis of his theory Thomson has shown that out of Q_o electrons starting from P the number that can travel x cm. through the air without combining to form ions is given by

$$Q/Q_o = e^{-(Wx)/(nK'LV/d)} \qquad (2)$$

where W is the velocity of thermal agitation of the electron, K' is the mobility of the electron, L is its mean free path, V is the voltage, d is the distance between the plates, and n is the chance of ion formation per impact.

Let us assume that when the voltage V is equal to V_0 *all* the Q_0 carriers starting from P at atmospheric pressures can reach E. This simplifying assumption is contrary to fact for at V_0 the carriers actually only *begin* to reach E. We may with this assumption impose the conditions implied in equation (1) on the equation (2). This will lead to the conclusion that out of a maximum possible current I_0, the real current I which reaches E as a function of the frequency $N = 1/T$, the pressure p, the plate distance d, and the voltage V, is given by the equation

$$I = I_0 e^{-\frac{W}{nK'L}\left(\frac{d^2(p/760)^2}{V} - \frac{K(p/760)}{N}\right)} \qquad (3)$$

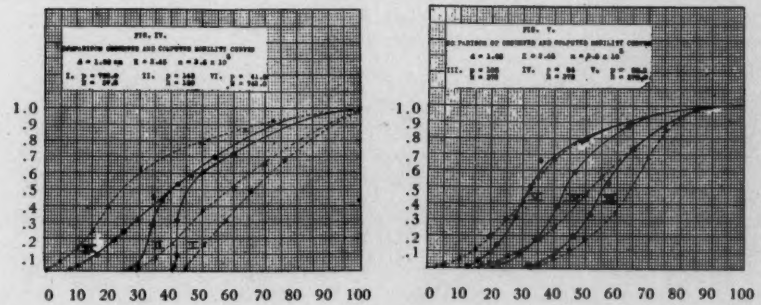
where p is in mm. of mercury, and K is the mobility of the normal ion. Now it is possible to evaluate W from the mean kinetic energy of the molecules, for it is assumed in the theory that the electrons move in the electric field with a velocity small compared to W. Let us further assume K' to be constant and equal to 200 cm./sec.,[7,8] while we take L as $4\sqrt{2}$ times the mean free path of the molecules, and K as about 2.5. We thus have the equation

$$I = I_0 e^{-\frac{9.9 \times 10^8}{n}\left(\frac{d^2(p/760)^2}{V} - \frac{(2.5p/760)}{N}\right)} \qquad (4)$$

This equation is open to experimental verification for it contains but one unknown quantity n, as I/I_0 can be determined experimentally under known conditions of N, p, V and d.

I have recently made a series of determinations of the mobilities of the carriers produced in air at different pressures under essentially the simple conditions in the foregoing discussion. These determinations yielded mobility curves of which the set of curves shown in figure II are typical. As is seen at once the form of the curves resembles the curves to be expected from the qualitative discussion above. The values of I/I_0 may be determined in such curves from the ratio of the current to E caused by a given alternating potential between P and E and that caused by an equal fixed negative potential on P. By substituting this value of I/I_0 in the equation with the corresponding values of N, P, V and d one may solve for n. As the result of a large number of determinations the value of n obtained under conditions best conforming to the theoretical assumptions was 250,000. With n determined the theory may be further tested by computing the curves for I/I_0 as a function of V for different values of d, N and p. A large number of curves were thus computed. A typical comparison of the theoretical curves so obtained and the curves actually observed under the same conditions may be seen in figures III, IV and V.

The dotted curves are the observed and the full curves are the computed ones. The experimental data are given in the legend. The shapes of the curves at atmospheric pressures or at low values of N, where the carriers are all ions, should not agree. For in deducing the theory we assumed that at V_0 *all* carriers succeeded in reaching E, which is not the case in fact. Also at the lower pressures close agreement is not to be expected, for the velocity acquired in the field becomes commensurable with the velocity of agitation W. Barring these points the general shapes of the theoretical and observed curves, and the changes in shape of these curves with p and N, are quite similar. It is also evident that the points of in-



flection, or the asymptotic feet, of the corresponding observed and computed curves fall on values of V which lie close together. This means that the values of the hybrid, or abnormal, mobilities estimated from the two sets of curves are nearly the same. There is, therefore, sufficient similarity in the two sets of curves to permit one to assert that the curves are represented by the same type of equation. We may then conclude that the Thomson theory is in *good qualitative* agreement with the results observed.

With the evidence before us I believe we are justified in concluding that the mechanism of negative ion formation in air consists in the electron attaching itself to a molecule to form a negative ion on the average in one out of 250,000** molecular impacts. Now it has been shown that in pure nitrogen[3,4] the electron does not attach to form an ion to any appreciable extent. We must, therefore, assume that the electron attaches to the oxygen molecule in air. Measurements made in pure oxygen give n as about 50,000. As there are four molecules of nitrogen in air to one of oxygen this agrees quite well with our conclusion. What the significance of n is, whether it depends on the electronic ring in the molecule struck, whether it depends on some particular state of the molecule struck, or whether it depends on the energy conditions of the impact remains for the future to say.

In conclusion I desire to express my thanks to Professor R. A. Millikan for his kind advice and criticism.

* A more detailed description of these experiments will later appear in the *Physical Review*.

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§ Such mobilities have been obtained below 100 mm pressures in air by all the experimenters in this field up to the time of Wellisch. Until Thomson proposed his theory they had never been adequately explained.

** This value depends on the correctness of the assumptions as to the numerical values of K' and L for the electron.

[1] Thomson, J. J., *London Phil. Mag.*, Sept., 1915.

[2] Kovarik, A. F., *Physic. Rev., Ithaca*, **30**, 1910 (415).

[3] Franck, J., *Verh. deuts. physik. Ges.*, **12**, 1910 (613).

[4] Loeb, L. B., These PROCEEDINGS, June, 1920.

[5] Loeb, L. B., *Physic. Rev.*, **8**, 1916 (6).

[6] Yen, K. L., *Ibid.*, **9**, 1918 (5).

[7] Wellisch, E. M., *Amer. J. Sci., New Haven*, (Ser. 4) **44**, 1917 (1); *Phil. Mag.*, **34**, July, 1917.

THE BASAL METABOLISM OF GIRLS 12 TO 17 YEARS OF AGE

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Read before the Academy, November 17, 1920

The Nutrition Laboratory's task of charting the field of basal metabolism of humans from birth to old age has resulted in a reasonable completion of the study of boys and girls from birth to puberty, of both sexes, from the college age to 35 years, and of women about 50 years of age. The metabolism during the important age-range from 12 to 17 years, representing as it does a period of rapid growth as well as the period of the establishment of puberty, has recently been studied, so far as girls are concerned, in a large respiration chamber permitting the simultaneous measurement of the carbon-dioxide production of a dozen or more subjects. Groups of twelve Girl Scouts each volunteered as subjects, and a typical experiment involved their entering the respiration chamber after a light standard supper and sleeping quietly throughout the night. The entire carbon-dioxide production during the period of "bed rest," as well as the "minimum" carbon-dioxide production found throughout the night, are the bases for the computations of the energy needs for "bed rest" and for the basal metabolism. The quiet, resting morning pulse rate was obtained with all groups and the insensible perspiration was also measured with most of the groups.

Special interest centres around the gaseous metabolism or, more particularly, the energy computations therefrom. It was found that 55.0 calories represented the average hourly heat production per individual, with very little difference due to either average age or average weight.

For groups of girls, therefore, from 12 to 17 years of age the energy requirement for 10 hours of "bed rest" may be taken as 550 calories. The basal 24-hour heat production with all these groups of girls closely approximated 1250 calories per individual, irrespective of age or weight.

The computation of the heat per kilogram of body weight per 24 hours, the classic method of equalizing, in so far as possible, differences in the weights of the groups, showed that in general the younger the average age, the higher the heat production. Similarly, computations of the heat production per square meter of body surface (obtained from the Du Bois height-weight chart) indicated a distinct tendency for the higher values to be found with the younger girls. These data for the basal metabolism measurements are given in table 1 herewith.

TABLE 1

BASAL HEAT PRODUCTION OF GIRLS 12 TO 17 YEARS OF AGE

DATE[1]	AVERAGE AGE		AVERAGE BODY WEIGHT WITHOUT CLOTHING	AVERAGE HEIGHT	BASAL HEAT (COMPUTED)[2] PER 24 HOURS		
					Per individual	Per kilo	Per sq. m.
1920	Yrs.	Mo.	Kgs.	Cms.	Cals.	Cals.	Cals.
Jan. 2–3	17	0	58.1	163	1258	21.7	777
Jan. 9–10	15	10	53.6	163	1170	21.8	745
Jan. 16–17	14	10	49.9	160	1254	25.1	830
April 9–10	14	1	44.2	155	1266	28.6	911
March 19–20	14	0	51.7	161	1331	25.7	876
Jan. 23–24	13	8	50.0	159	1382	27.6	928
Feb. 13–14	13	4	43.7	153	1188	27.2	867
March 12–13	12	10	41.0	152	1226	29.9	922
March 5–6	12	2	39.5	150	1180	29.9	915

[1] Eleven girls were studied on Jan. 16–17 and April 9–10; 12 girls on all other dates. All girls in the 15, 16 and 17 year old groups had reached puberty; none of the girls studied on April 9–10 and March 12–13 had reached puberty; 5 girls on Jan. 23–24, 2 on March 19–20, 4 on Feb. 13–14, and 11 on March 5–6 had *not* reached puberty.

[2] Using a respiratory quotient of 0.79 and 3.086 calories as the calorific equivalent of a gram of carbon dioxide.

The striking influence of age is shown by the values for the heat production per kilogram of body weight, which indicate a specific high metabolism with the younger ages. These values for the heat per kilogram have been plotted, referred to age, in figure 1, and a line representing the general trend of the metabolism has been laid on the chart. From this chart we have derived the predicted values for the heat per kilogram of body weight of girls, depending upon age, and these values we present in table 2 as representing the best available standard for predicting the heat production of young girls of this age-range.

TABLE 2

BASAL HEAT PRODUCTION PER KILOGRAM PER 24 HOURS PREDICTED FROM AGE, FOR GIRLS FROM 12 TO 17 YEARS OF AGE

AGE	PREDICTED HEAT PER KILO. PER 24 HOURS
YRS.	CALS.
12	30.9
12½	29.9
13	28.8
13½	27.7
14	26.7
14½	25.7
15	24.6
15½	23.6
16	22.6
16½	21.7
17	21.2

Other general conclusions derived from the study are the following: The average, minimum, resting pulse rate per minute of girls from 12 to 17 years of age, just before rising in the morning, was found to be 81 at 12 years, 77 at 13 years, 77 at 14 years, 83 at 15 years, 71 at 16 years, and 74

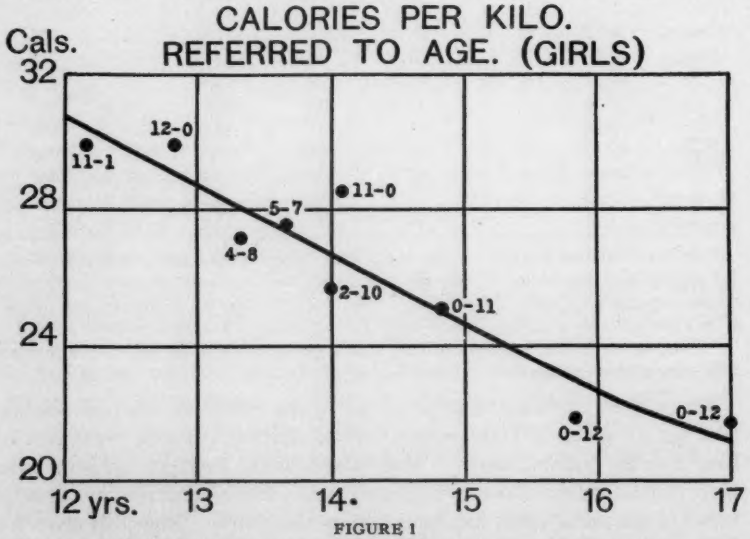

FIGURE 1

Basal heat production of girls per kilogram per 24 hours referred to age

The first of the two figures accompanying each point on this chart represents the number of girls in the group who had *not* as yet menstruated; the second figure indicates the number who had.

at 17 years. The insensible perspiration for these girls per kilogram of body weight per hour was as follows: 0.72 gram at 13 years, 0.71 gram at 14 years, and 0.77 gram at 15 years. The respiratory quotients of groups of 12 girls each, about 7 to 8 hours after a light meal, were 0.81, 0.81, 0.78, and 0.79.

The basal heat production per kilogram of body weight per 24 hours decreases regularly with increasing age from 29.9 calories at 12 years 2 months to 21.7 calories at 17 years. The heat production per square meter of body surface per 24 hours likewise decreases, but not so regularly, with increasing age, ranging from 928 calories at 14 years to 745 calories at 16 years.

The metabolism of groups of young girls can be predicted from the general curve indicating the heat production per kilogram of body weight referred to age to within an average error of $\pm 3.1\%$. The prediction of the heat production per unit of body weight is somewhat better than that per unit of surface area. The curves representing the heat production per kilogram of body weight referred to weight and per square meter of body surface referred to weight for these groups of girls from 12 to 17 years of age blend with remarkable uniformity with similar curves based upon the measurement of a large number of normal girls from birth to 12 years of age.

No influence of puberty or the prepubescent stage is clearly proven in any of the results.

The details of the entire research are shortly to appear in the *Boston Medical and Surgical Journal*.

ON THE REFLECTION AND RE-EMISSION OF ELECTRONS FROM METAL SURFACES: AND A METHOD OF MEASURING THE IONIZING POTENTIAL OF SUCH SURFACES

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Read before the Academy, November 16, 1920

In making photo-electric measurements upon suspended droplets of mercury, one of us has repeatedly found that photo-electrons are always released when the droplet is illuminated by the ultraviolet line of wave-length 2536 Angstroms. On the other hand, it has been frequently proved that the molecules of mercury vapor are not ionized at all by these wave-lengths. The quantum of energy, then, which must be incident upon mercury in the liquid form in order to detach electrons from it is quite different from that required to detach electrons from the free atoms. It is to be expected from this fact that the "ionizing potential" also of liquid mercury will be quite different from that of the same element in

the gaseous form. A considerable group of investigations has accordingly been begun in the Ryerson Laboratory for the purpose of determining, in the best vacua obtainable with modern means, the effect of surface conditions upon the emission of electrons from solids and liquids. Preliminary results from one of these investigations are reported herewith.

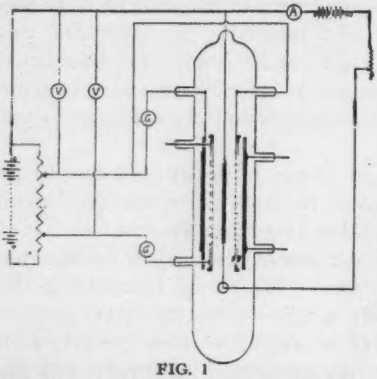

FIG. 1

The aims sought were:

1. To differentiate between the primary electrons which are reflected from a copper surface, and those which are emitted by such a surface because of the bombardment of the primaries.

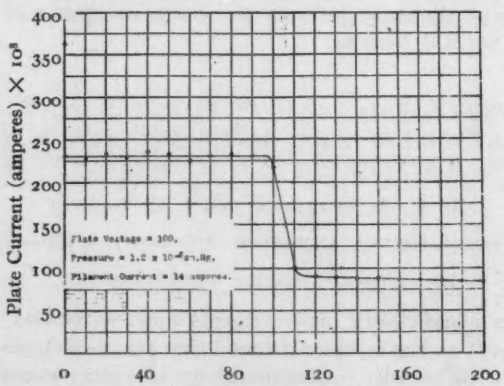

FIG. 2

2. To determine the exact potential at which the surface begins to re-emit under such bombardment. This will be called the ionizing potential of the surface.

3. To determine the number of electrons re-emitted per impinging electron as a function of the energy of impact.

4. To remove surface films by heat and to determine the effect of such films both upon the critical potential (2) and upon the amount of re-emission (3).

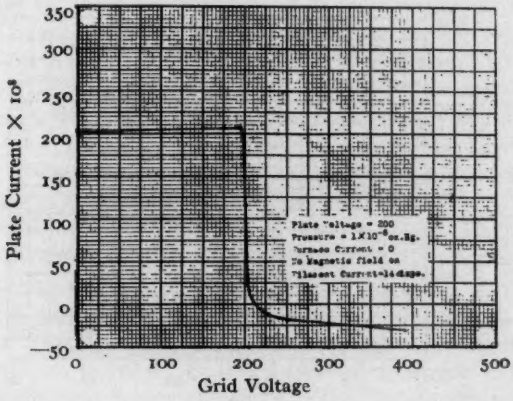

FIG. 3

5. To determine the effect of temperature alone upon the critical potential and the amount of re-emission after the surface had been well cleaned by the method of (4).

The apparatus designed in the endeavor to realize these aims and with which the following results have been obtained is shown, reduced to one-fourth natural size, in figure 1.

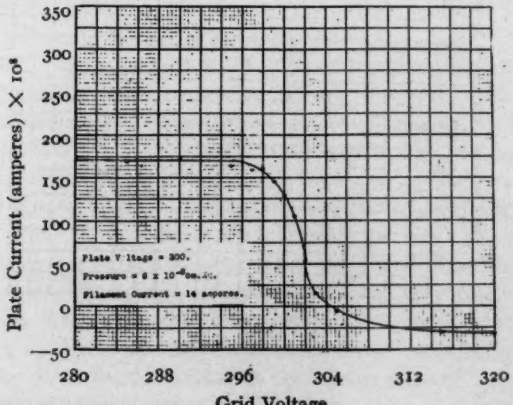

FIG. 4

The thermionic emittor consists of a central platinum cylinder 3 mm. in diameter, coated with the oxides of barium and calcium, and heated indirectly by a central tungsten wire (No. 22) from which it is separated

by alundum cement. The emittor is thus *an equipotential surface.* Concentric with this emitting surface is a copper cylinder, *s*, 1.8 cm. in diameter, which will be called grid No. 1. About one-fiftieth part of its surface

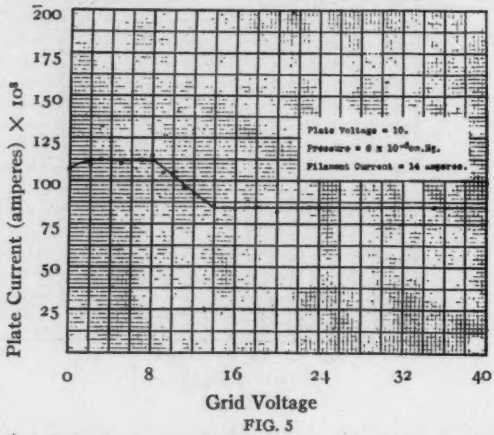

FIG. 5

is perforated with holes, uniformly placed, 1 mm. in diameter. Just outside this cylinder and insulated from it by quartz or porcelain rings 1 mm. thick is a second clyindrical grid, *g*, the holes of which are slightly larger

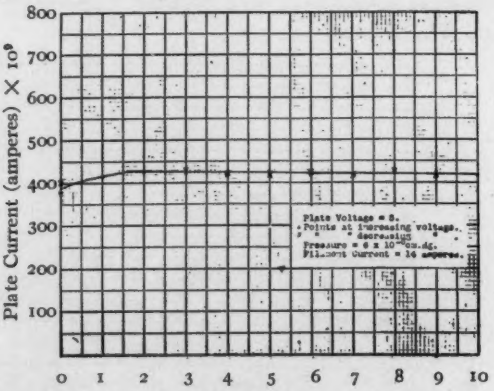

FIG. 6.

(3 mm. in diameter) but exactly match those of grid No. 1. Outside this is a third cylinder of copper, 3 cm. in diameter, which will be called the plate. The plate can be heated by means of a coil of nichrome wire wrapped about it but insulated from it with a soap-stone coating 2 mm. thick.

In the following observations the plate and grid No. 1 are kept at a common potential and both at a fixed potential, e. g., 100 volts, above the emittor. Figure 2 shows the curve obtained when the plate-current is plotted against the potential of grid No. 2 as the potential of the latter is varied from 0, the potential of the filament, up to 200 volts. When the potential of grid No. 2 has risen above that of grid No. 1, that is, above 100 volts, the secondary electrons, emitted by the plate under the bombardment of the primary electrons having an energy of 100 volts, are drawn from the plate to grid No. 2 and thus reduce the current flowing to the plate. Further, the difference between the two constant currents above and below the 100 volt value of abscissae is a measure of the secondary electrons which are attracted back from the plate. The ratio of this difference to the initial constant plate-current gives the number of secondary electrons produced at the plate per primary electron.

Again the difference between 100 volts and the potential at which the current begins to descend (see fig. 2) gives the maximum velocity of emission of secondaries in volts. Figures 3 and 4 show similar curves taken with primary electrons having energies of 200 and 300 volts, respectively, the latter being made with largely expanded abscissae so as to permit of a study of the distribution of velocities of the secondary electrons. It will be seen from figure 4 that practically no secondaries have a velocity of more than 5 volts, even when the exciting primary electrons have velocities of 300 volts. Further, figure 4 shows, since the potential reaches 310 volts before the current is again constant, that about 10 volts are required to pull out of the plate all of the secondaries generated. This is doubtless due to the fact that some of them are shielded by, or lost in, the pits and hollows in the surface of the plate.

Figures 5 and 6 show the curves obtained with primary electrons having energies of 10 and 5 volts, respectively. It will be seen that the maximum velocity of the secondaries obtainable from figure 5 is 2 volts. *The failure of the curve of figure 6 to drop at all as the potential of grid No. 2 passes through 5 volts seems to show conclusively that none of the 5 volt incident electrons are reflected, and also that the ionizing potential of the surface is above 5 volts; while figure 5 shows that it is below 10 volts.*

The accompanying table shows how the coefficient of secondary emission depends upon the energy of impact of the primary electrons in the case of a copper surface which had been subjected to red-hot temperatures for many hours. The coefficients were some 30% less before such treatment. On the other hand, increase in the temperature of the plate after treatment appeared to decrease the coefficient.

TABLE I

Impact voltage.....	5	7	10	15	20	25	50	75	100	150	200	250	300	400	500
Coef. of secondary emission.....	0	.08	.22	.30	.34	.40	.46	.58	.65	.86	1.00	1.10	1.26	1.25	1.25

The important results so far obtained from this work, which is still in progress, may be summarized as follows:

1. Contrary to current belief,[1] there appears to be no such phenomenon as the *direct reflection of* an electron from a copper surface, or if the phenomenon exists at all, the number so reflected at potentials less than the ionizing potential is negligible.

2. The result obtained in (1) reveals, therefore, a method of determining with simplicity and with considerable accuracy the ionizing potential of a metal surface. (The careful determination of the values of such potentials is now being carried out.)

3. As the energy of electronic impact increases, the amount of reemission from copper increases up to about 300 volts, from which point on it remains essentially constant.

4. In the case of copper, the number of electrons detached per impinging electron is never found to exceed 1.3.

5. The number of secondaries per electron is somewhat increased by cleaning the surface by heat, and it appears to be somewhat decreased when the temperature of the surface is raised.

6. The maximum energy of emission of electrons released by electronic bombardment of copper increases from about 2 volts to about 5 volts as the energy of impact increases from 10 volts to 300 volts.

The full details of this work will be reported by one of us in a more extended article in the *Physical Review*.

[1] von Baeyer, O., *Verh. deut. physik. Ges., Berlin*, **10**, 1908 (903); also Gehrts, A., *Ann. Physik., Leipzig*, **36**, 1911 (996). Horton and Davies, *Proc. Roy. Soc.*, **97**, 23, 1920, obtained results which they interpret in terms of reflections, but which we do not think demand such interpretation. The article by Hull, A. W., *Proc. Inst. Radio Engineers*, Feb., 1918, should also be read, though it does not bear upon this particular point.

CHRONOLOGY OF THE SAN JUAN AREA

By Earl H. Morris

American Museum of Natural History, New York

Communicated by H. F. Osborn, December 2, 1920

The chronological outline herein presented is the result of ten years' research among prehistoric aboriginal remains in that portion of the San Juan watershed lying in northwestern New Mexico, southwestern Colorado, and adjacent areas in Arizona and Utah. In the earlier stages of the work, financial support was given successively by the School of American Archaeology, the St. Louis branch of the Archaeological Institute of America, and the University of Colorado. For the past five years the work has been under the direction of the American Museum of Natural History as a part of the Archer M. Huntington Survey of the Southwest.

Approximately 250 archaeological sites have been visited and examined, 148 of them intensively. The distribution of the letter is as follows:

Immediate valley of the San Juan	22
East and south side of river:	
Canyon Frances	3
Canyon Gobernador	12
Canyon Largo	1
Kootz Canyon	1
Chaco Valley	22
Eastern slope, Tunicha Mountain	20
North side of river:	
Animas Valley	27
La Plata Valley	14
Between La Plata and Mancos rivers	26

For the present, the San Juan culture area may be considered coextensive with the watershed of the river whence it takes its name. This area is some 25,000 square miles in extent. It is a vast elevated plateau cut through by a few perpetual streams and numerous cliff-bordered washes which flow only during spring thaws or subsequent to heavy rains. Despite its general aspect of intense aridity, aboriginal culture flourished over the entire area to the extent that almost every locality capable of supporting an agricultural people is marked by ruins large or small. These remains belong to four major cultural horizons, in stratigraphic order as follows:

IV. Late Black-on-white
III. Early Black-on-white
II. Pre-Pueblo
I. Basket Maker

1. *Basket Maker Period.*—The chief diagnostic characters of Basket Maker culture are: Pronounced dolichocephalic crania, without artificial occipital flattening; apparent total absence of permanent habitations; absence of bow and arrow; use of *atlatl;* high development of textile manufacture, with specialized types of sandals and burial baskets; absence of pottery; and the cultivation of one very primitive type of corn.

Remains of the Basket Maker period have been found only in a restricted area, all identified sites being within a radius of twenty-five miles of Bluff City, Utah. This region has been intensively worked by Dr. A. V. Kidder and Mr. Samuel H. Guernsey. Hence, to them belongs the credit for having identified and characterized this initial culture stratum.

2. *Pre-Pueblo Period.*—Crania from pre-Pueblo sites are for the most part dolichocephalic, like those of the Basket Makers; but among them there are a minority of what appear to be brachycephalic crania with artificial occipital flattening, such as is typical of the subsequent periods.

Pre-Pueblo dwellings were flimsy, irregularly arranged, one-storied structures, with walls usually composed of poles set upright and plastered with mud. Occasionally, however, the basal portions of walls were faced with stone slabs set on edge, or more rarely, a wall was raised of crude masonry. Within the area of or adjacent to the buildings were circular subterranean or semi-subterranean chambers whose walls were formed by the sides of the excavated pits. These chambers were the prototype of the later kiva.

Perishable materials have not been recovered from this period. Pottery was made and commonly used, but both forms and ware were crude. Smooth ware predominated over corrugated, which is doubtfully present. On the average less than thirty per cent of the smooth ware bears painted decoration.

Pre-Pueblo remains have been found in every ruin-strewn locality where a search for them has been made. The sites occur singly and in groups, usually in open, unprotected places. As type sites may be mentioned those upon the mesas between the La Plata and Mancos rivers described elsewhere (Thirty-third Annual Report, Bureau of American Ethnology, Washington, 1919).

3. *Early Black-on-white Period.*—Crania from the early black-on-white period are all of apparent brachycephalic type with artificial occipital flattening. Dwellings of this period are more numerous and more widely distributed than those of earlier or later types. Both large and small structures occur, the latter being more common. Stone was the building material generally used, but the individual blocks were never faced. In some cases the buildings may have been more than one story in height. The usual forms are rectangular, L or E-shaped. Circular subterranean chambers possessing all diagnostic kiva characters form a component part of every dwelling.

The textiles of this period are in every sense of Pueblo type. There is no remaining trace of the specialized Basket Maker bags, burial baskets, and square-toed sandals. At least three types of corn were cultivated. Ceramics was highly developed, both smooth and corrugated ware being very abundant. Certain forms of smooth ware, such as pitcher-shaped drinking vessels, and half-gourd ladles, and the absence of exterior decoration on bowls, are characteristic. Corrugated ware reached its highest development, as expressed by wide range of forms and extreme variety of decoration produced by the manipulation of the coils.

No early black-on-white site has been thoroughly excavated; hence, a type site remains to be described.

4. *Late Black-on-white Period.*—Crania from the late black-on-white period are, in superficial appearance, like those from the preceding period; that is, short from back to front with artificial occipital flattening.

Ruins belonging to this period are relatively few in number, but are

generally of large size. Typically, they are compact massive structures, two, three, and four or more stories in height, rising terrace fashion from an enclosed court. Stone was the customary building material. Many of the blocks were faced with admirable precision, and some of them were even polished. Kivas occurring as components of these structures are of large size, highly elaborate, and of unsurpassed construction. They are situated both within the enclosed courts and incorporated within the main building masses, the former subterranean, the latter above ground, and in some cases raised.

Specialization in architecture is much in evidence, several distinct local types, each distributed over a continuous minor area, being recognizable. The two prevailing localized forms are the cliff-houses, Mesa Verde as the type, and the great houses of the Aztec-Chaco region, the large ruin at Aztec, New Mexico, now nearing complete excavation by the writer, as the type specimen.

Cloth, basketry, and sandals are in every known respect identical with those of the preceding period. Smooth and corrugated ware continued through late black-on-white time; smooth ware reached the zenith of its perfection, while corrugated ware began to degenerate. Local specialization in pottery was a direct accompaniment of specialization in architecture. There are at least three major local types of pottery, namely, the Kayente, the Mesa Verde, and the Chaco, each with diagnostic forms and styles of ornamentation.

The following is a tentative interpretation of the data given above. In the Basket Maker period there is evidence of a dolichocephalic people, skilled makers of textiles, but ignorant of the utilitarian possibilities of clay and of the use of the bow and arrow. They were essentially nomadic, without permanent dwellings, but undergoing transition to sedentary life under the compelling influence of the cultivation of corn, of which they had a single primitive type.

In the pre-Pueblo period there may be postulated the blending of a brachycephalic element with the previous dolichocephalic stock. In this period a crude architecture was developed, the bow and arrow were introduced, and the manufacture of pottery begun.

In the early black-on-white period the brachycephalic stock seems entirely to have supplanted the dolichocephalic. Diagnostic Pueblo architecture expressed in fairly compact structures consisting of rectangular living rooms and circular ceremonial chambers, had taken definite form. Agriculture had been amplified by the addition of at least two types of corn and pottery making had been developed into a fine art.

In the culminating, or late black-on-white period, there are no evident changes in physical characteristics. Some potent integrating force, perhaps the pressure of predatory nomadic intruders, had brought together the hitherto widely scattered population into a few large and power-

ful groups. These groups, in their several localities, carried Pueblo culture to its highest material perfection, at which point, for reasons as yet undetermined, Pueblo occupation of the San Juan area came to an abrupt close. As a terminating phase of late black-on-white time, there came a period of redistribution during which Pueblo culture was carried to the east, south and west.

The correlation of specific San Juan chronology with the chronology of the southwest as a whole is a work much of which is still to be done. The only other portion of the southwest for which a definite chronology has been proposed is that for the upper Rio Grande Valley in New Mexico. This area is both historic and prehistoric, in contrast to the area of the San Juan, which is exclusively prehistoric. Thus, the systematic series for the former presents a sequence, part of which can be historically dated, as established by Mr. N. C. Nelson and Dr. A. V. Kidder. The chronology of this Rio Grande area contains the following major divisions:

5. Modern Painted Ware
4. Historic Two-Color Glazed Ware
3. Three-Color Glazed and Painted Ware
2. Two-Color Glazed Ware
1. Two and Three-Color Ware

No. 1 of this series is comparable to IV in the San Juan series. Our data may, therefore, be interpreted as indicating a shift of cultures from the San Juan to the Rio Grande. Since ceramic types are but the horizon markers for the cultural epochs to which they belong, the chronologies for the San Juan and the Rio Grande areas may be combined and re-cast as in the following:

1. Basket Maker, or Initial Period
2. Pre-Pueblo, or Formative Period
3. Early Two-Color Painted Ware, or Period of Development
4. Late Two-Color Painted Ware, or Period of Culmination and Redistribution
5. Two-Color Glazed Ware
6. Three-Color Glazed and Painted Ware
7. Historic Two-Color Glazed Ware

It appears, therefore, that the establishment of a chronological scale for the area of the San Juan gives us a succession of cultural periods during the greater part of the prehistoric period for the southwest.

A full description of the sites examined, together with a formulation of the evidence upon which the preceding chronological sequence rests will be presented in future numbers of the *Anthropological Papers of the American Museum of Natural History.*

SOME GEOLOGIC CONCLUSIONS FROM GEODETIC DATA

BY WILLIAM BOWIE

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Communicated by A. O. Leuschner. Read before the Academy, November 16, 1920

For a number of years geodetic data were collected for the purpose of controlling surveys and maps and for the determination of the shape and size of the earth. But in recent years they are also extensively used in investigations dealing with geological and geophysical problems. These investigations have included data for the United States, India, Canada and a small part of Europe.

The investigations in isostasy have proved that for the areas considered there is approximately the same mass in each column of unit cross-section extending from the surface of the earth down to a depth of, say, 75 miles. This statement is justified regardless of what the depth of compensation actually is, for the deficiency or excess of mass in a few miles at the depth of approximately 75 miles is a small percentage of the mass of the whole column. With regard to depth of compensation it may safely be said that there is no sharply defined surface which is at uniform depth below sea level, limiting the isostatic compensation. It is probable that there is a zone, rather than a surface, which limits the compensation.

We have no evidence as to the manner in which the compensation is distributed vertically, but the uniform distribution, which was adopted in order to make the computations more feasible, is as logical as any other simple method. Regardless of what the method of distribution is actually, the conclusions reached from the isostatic researches cannot be seriously affected.

What is the area of the cross-section of the unit column that may be in equilibrium is a matter which is in doubt, but as data are accumulated the area of the cross-section is successively lessened.

It has been found that large areas are in almost perfect isostatic balance and it seems to be very probable that an area of about 70 miles square is very closely compensated. This is the area of one square degree at the equator, or very nearly so.

It has been found that the distribution of the compensation of a topographic feature horizontally to a distance of about 60 kilometers from the feature gives as consistent results as local compensation, but when the compensation is distributed horizontally to a distance of 170 kilometers the results are not so accordant as with local distribution of the compensation.[1]

It must be held that any system for correcting geodetic data for the effect of topography and isostatic compensation, which makes the computed values of gravity agree closely with the observed values in different

EFFECT OF GRAVITY ANOMALIES OF THE COMPENSATION FOR INNER ZONES

NUMBER AND NAME OF STATION	ELEVATION H	ISOSTATIC ANOMALY IN DYNES	COR. TO DISCARD COMP. OUT TO AND INCLUDING		ANOMALIES WITH ISOSTATIC COMP. OMITTED TO	
			Zone L. (17.9 mi.) In dynes	Zone M. (36.5 mi.) In dynes	Zone L. In dynes	Zone M. In dynes
	Meters					
41 Wallace, Kans.	1005	−0.012	−0.027	−0.048	−0.039	−0.060
42 Colorado Springs, Colo.	1841	−0.007	−0.054	−0.094	−0.061	−0.101
43 Pikes Peak, Colo.	4293	+0.021	−0.070	−0.113	−0.049	−0.092
44 Denver, Colo.	1638	−0.016	−0.038	−0.076	−0.054	−0.092
45 Gunnison, Colo.	2340	+0.020	−0.063	−0.120	−0.043	−0.100
46 Grand Junc., Colo.	1398	+0.024	−0.041	−0.082	−0.017	−0.058
47 Green River, Utah	1243	−0.021	−0.033	−0.067	−0.054	−0.058
48 Pleasant Val. Junc., Utah	2191	+0.004	−0.060	−0.103	−0.056	−0.099
49 Salt Lake City, Utah	1322	+0.010	−0.040	−0.075	−0.030	−0.065
50 Grand Canyon, Wyo.	2386	−0.002	−0.061	−0.108	−0.063	−0.110
51 Norris Geyser Basin, Wyo.	2276	+0.021	−0.059	−0.104	−0.038	−0.083
52 Lower Geyser Basin, Wyo.	2200	−0.001	−0.058	−0.103	−0.059	−0.104
55 Mt. Hamilton, Cal.	1282	−0.003	−0.014	−0.017	−0.017	−0.020
63 El Paso, Tex.	1146	+0.007	−0.030	−0.054	−0.023	−0.047
64 Nogales, Ariz.	1181	−0.050	−0.029	−0.046	−0.079	−0.096
67 Goldfield, Nev.	1716	−0.013	−0.043	−0.074	−0.056	−0.087
68 Yavapai, Ariz.	2179	+0.001	−0.045	−0.080	−0.044	−0.079
70 Gallup, N. Mex.	1990	−0.013	−0.053	−0.095	−0.066	−0.108
71 Las Vegas, N. Mex.	1960	+0.003	−0.053	−0.094	−0.050	−0.091
75 Lead, S. Dak.	1590	+0.052	−0.038	−0.064	+0.014	−0.012
81 Sisson, Cal.	1048	−0.010	−0.033	−0.058	−0.043	−0.068
82 Rock Springs, Wyo.	1910	+0.013	−0.052	−0.093	−0.039	−0.080
98 Alpine, Tex.	1359	+0.021	−0.034	−0.061	−0.013	−0.040
99 Farwell, Tex.	1259	−0.016	−0.030	−0.055	−0.046	−0.071
102 Cloudland, Tenn.	1890	+0.004	−0.025	−0.039	−0.021	−0.035
109 Sheridan, Wyo.	1150	+0.032	−0.032	−0.068	0.000	−0.036
110 Boulder, Mont.	1493	−0.015	−0.046	−0.077	−0.061	−0.092
114 Truckee, Cal.	1805	−0.028	−0.051	−0.085	−0.079	−0.113
115 Winnemucca, Nev.	1311	−0.009	−0.032	−0.062	−0.041	−0.071
116 Ely, Nev.	1962	−0.021	−0.055	−0.094	−0.076	−0.115
117 Guernsey, Wyo.	1322	+0.036	−0.031	−0.062	+0.005	−0.026
195 Lander, Wyo.	1635	+0.019	−0.047	−0.090	−0.028	−0.071
198 Edgemont, S. Dak.	1066	+0.054	−0.028	−0.052	+0.026	+0.002
202 Moorecroft, Wyo.	1295	+0.021	−0.031	−0.058	−0.010	−0.037
269 Hill City, S. Dak.	1518	+0.042	−0.040	−0.067	+0.002	−0.025
270 Newcastle, Wyo.	1328	+0.029	−0.035	−0.064	−0.006	−0.035
271 Bridgeport, Neb.	1114	−0.008	−0.029	−0.053	−0.037	−0.061
272 Buford, Wyo.	2396	+0.046	−0.057	−0.100	−0.011	−0.054
273 Boulder, Colo.	1630	−0.014	−0.048	−0.092	−0.062	−0.106
274 Lafayette, Colo.	1595	−0.020	−0.040	−0.081	−0.060	−0.101
275 Brighton, Colo.	1511	−0.006	−0.038	−0.073	−0.044	−0.079
276 Idaho Springs, Colo.	2303	+0.022	−0.068	−0.120	−0.046	−0.098
Mean with regard to sign		+0.005	0.043	0.077	−0.037	−0.072
Mean without regard to sign		0.019			0.040	0.072

parts of the earth and for various types of topography, is very close to the ideal or true system. While the isostatic investigations have been confined to only a portion of the earth's surface it seems probable that all land areas will be found to be in isostatic equilibrium.

A test was made to show whether the compensation of small areas of topography could be ignored without seriously affecting the results. Forty-two stations having high elevations were selected for the test. The elevations of these stations varied from 3000 to 14,000 feet. When the compensation of the topography for a circle with a radius of 17.9 miles was ignored the gravity anomalies became much larger and 37 of the 42 anomalies had negative signs. When the area of the circle was given a radius of 36.5 miles the anomalies were still further increased and all of the anomalies except one had the negative sign. With the small circle the mean anomaly with regard to sign is -0.037 dyne while with the larger circle the mean anomaly with regard to sign is -0.072 dyne. When it is considered that the mean anomaly with regard to sign for these 42 stations under consideration, all at high elevations, is only $+0.005$ dyne, it is realized that the ignoring of the local compensation is not justified. The table preceding shows these results.

This test shows that, for even very small areas, the topography is at least largely compensated. This is a most important conclusion for by analogy no such mass as the sedimentary material forming the delta of a large river entirely escapes isostatic compensation as has been held by some investigators.[2]

There are very definite relations between the gravity anomalies and the Cenozoic and Pre-Cambrian formations. The Cenozoic stations have negative anomalies in nearly all cases, and the largest anomalies are found at stations located on this formation. The anomalies at the stations on the Pre-Cambrian areas of limited extent are nearly all positive.[3]

The writer made an investigation of these relations and arrived at the conclusion that the negative sign of the Cenozoic anomalies is due in great part to the abnormally light material of that formation. Of course it is necessary to consider the effect of the Cenozoic material which extends below sea level. Nearly all Cenozoic formations are at comparatively small elevations and the abnormal density of the material which may be above sea level could account for only a very small part of the anomalies at Cenozoic stations.

In a similar manner it was found that the existence of abnormally dense material in the Pre-Cambrian formation will account for the positive sign of the anomalies at stations on that formation. It will be necessary, as in the case of the Cenozoic formation, to consider the material that extends below sea level.

These are logical conclusions for it is not conceivable that with a whole country (the United States, for example) in practically perfect isostatic

balance, the column under an area of sedimentation should be too light and that the column under an area subjected to long erosion should be too heavy.

The writer's conclusion has been confirmed by a recent investigation in India.[4]

If the columns under the Cenozoic and the Pre-Cambrian formations are in isostatic equilibrium, then there must exist the compensation not only of the material which is above sea level but of the deficiency of matter in the Cenozoic and the excess of matter in the Pre-Cambrian material which exist below sea level.

It is inconceivable that 20,000 or 30,000 feet of sediment all deposited at a low elevation, approximately sea level, could take the place of an equal volume of material presumably of normal density and still have the column contain normal mass, without there having occurred an increase in density in the material of the column to balance the deficiency of mass in the volume occupied by the recent sedimentary material. If the Cenozoic material is 30,000 feet thick, the deficiency in mass is about 3000 feet, and the isostatic compensation will be equal to this amount. In the 75-mile column the increase in density necessary to balance the Cenozoic deficiency will be about $^3/_4$ of 1%, if we assume that the average density throughout the column is approximately three. If the density is greater than that, the percentage will be proportionately increased.

In order to maintain the isostatic balance a mass equivalent to 27,000 feet of Cenozoic material must have been transferred from the column under the Cenozoic formation.

The contraction of the material in the column under the Cenozoic formation may have begun before sedimentation was initiated, but further contraction and consequent increase in density must have taken place with the sedimentation for, otherwise, the surface of the column would have stood at some times much above sea level, which seems to have been improbable.

The evidence *available from geodetic investigations* indicates in the strongest way that land masses are in equilibrium and that this equilibrium exists in comparatively small areas. A natural inference is that land masses have been equally in equilibrium in former geologic periods.

How, then, can an area of sedimentation at approximately sea level, of one age, be a mountainous area in a succeeding one?

Mountain formation by transportation of material horizontally from one column in equilibrium to another column in equilibrium could not take place without destroying the isostatic balance. Of course, material is transported from one column to another (surface transportation after erosion is not included in this statement) but this is when the columns are out of balance and the movement renews the isostatic equilibrium between the two columns. Mountain masses are not excess loads on the earth, as is proved by the existence of the isostatic conditions in mountainous

regions, therefore the materials forming the mountains were not moved horizontally to the region. We are forced to the conclusion that the mountains must result from vertical movements in the columns under them. The vertical movement evidently must be due to an expansion and consequent decrease in density in the material of the column.

When we consider that all extensive areas of recent sedimentation on which we have gravity stations are in isostatic equilibrium and that mountain systems formed in previous sedimentary areas are also in equilibrium, we have no alternative to the view that an actual expansion of the columns under the mountains has taken place.

The objection will be raised that there is abundant evidence that there have been horizontal movements in the materials forming the mountains. This is granted but is it necessary to go far beyond the mountain area for the forces acting laterally which cause the observed horizontal movements? Can we not conceive that, in the uplifting of the mountains of the Appalachian and Himalayan systems, for instance, the vertically acting forces will cause the material to progress in the directions of least resistance and that these directions may be horizontal in some cases and in others at varying angles with the vertical.

During the period of sedimentation, material probably was not laid down in smooth concentric sheets but in irregular ways. In the process of uplift, due to expansion, the rate of expansion would undoubtedly be different in different parts of the zone. The sediments are of varying thickness, the material on which the sediment had been deposited varies in composition and consequently in its resistance to uplift, and finally there is cubical expansion of the material which must cause the material at the borders, but outside of the columns, to modify somewhat the upward movements of the expanding mass. At least this effect must be exerted near the upper part of the expanding column. The areas affected are not small for the area of the base of the Appalachian system is more than 1000 miles in length and is approximately 200 miles in width, on an average. Consequently, there seems to be sufficient space for the development of lateral movements within the area due to local causes.

The drowned valleys along the continental coasts show that decided subsidences have taken place. How could these have been caused except by contraction of the columns under the affected areas since the pendulum proves rather conclusively that the regions along the coasts are in isostatic equilibrium? Here the reverse process to that of mountain forming operated.

The writer has arrived at the conclusions here presented after endeavoring to harmonize geodetic data and certain observed geological facts. He makes no attempt to formulate a theory as to what agencies are at work to change the density of material far below sea level (but within, say, 75 miles of the surface), but he suggests that the vertical movements ac-

companying the isostatic adjustments may be a partial cause. Material is moved in this process, to zones of decidedly different temperatures, to hotter or to colder zones, and it seems to be logical to conclude that some chemical or physical changes may take place which would affect the density of the material transported. In the process of isostatic adjustment all the material of a column above the zone of flow is raised or lowered. The ordinary thermal expansion of the material of a column, as it changes its temperature, is capable of accounting for only a small part of the changes in the length of a column.

It should be clearly borne in mind that the theory of isostasy does not explain any vertical movements other than those necessary to maintain equilibrium. Some other theory is needed to explain elevation and subsidence and the writer feels that the theory of local expansion and contraction is in general in harmony with the geodetic data. He believes, however, that there are local vertical movements of small amounts which may not be due to these causes.

It is hoped that increased activity will take place in collecting geodetic data and in extending the investigations in isostasy. It is particularly desirable that we have the investigations include the ocean areas as soon as geodetic data may be available within them.

[1] See page 90, "Investigations of Gravity and Isostasy," *Spec. Pub. No.* **40**, *U. S. Coast and Geodetic Survey*, 1917.

[2] "Strength of the Earth's Crust," by Jos. Barrell, *J. Geol.*, January-February, 1914 (48); and "Discoidal Structure of the Lithosphere" by Bailey Willis, *Bull. Geol. Soc. Amer.*, June 30, 1920.

[3] "Investigations of Gravity and Isostasy," *Spec. Pub.* **40**, *U. S. Coast and Geodetic Survey*, pp. 70–82.

[4] "Investigations of Isostasy in Himalayan and Neighboring Regions," *Professional Paper No.* **17**, by S. G. Burrard, former Surveyor-General of India, 1918.

EXPERIMENTS ON THE ELECTRICAL CONDUCTION OF A HYDROGEN ALLOY

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Communicated by O. Veblen. Read before the Academy, November 17, 1920

In studies which were described some time since[1] it was found that hydrogen, when discharged electrolytically upon any one of certain metals which occlude it, produces a temporary diminution in the electrical resistance of the metal. With metals, such as palladium, which occlude large amounts, and suffer, as has long been known, a lasting *increase* of resistance, the diminution of resistance, or supplementary conductance, is superimposed upon the opposite and more enduring effect; while in the

case of platinum, which has only a small occlusive capacity, and does not display the permanent increase, the supplementary conductance may be observed alone.

Regarding the nature of this peculiar electrical conduction, three explanations seem thus far to offer:

(1) The conduction is by a transient form of the occluded hydrogen, probably monatomic, and consists in a transport of electrical charges between points of different potential within the metal.

(2) The conduction is by unstable hydrides, which are produced only under conditions of electrolysis which are equivalent to a high pressure of hydrogen, and which rapidly decompose when these conditions cease to obtain. (Newbery.)[2]

(3) The conduction, while not the result of chemical combination, is due to a temporary effect which the occluded hydrogen exerts upon the distribution or mobility of the electrons within the metal.

Upon the second or third of these suppositions, there appears to be no reason to expect the character of the supplementary conduction to differ from that of metallic conduction in general; but the first-named hypothesis leads to a different expectation.

This first explanation, which has been suggested by the observation that the supplementary conduction and the volume of the alloy are directly related, may be stated somewhat more in detail as follows:

It is supposed that within a hydrogen alloy there exist (*a*) molecular hydrogen, (*b*) atomic hydrogen, and (*c*) hydrogen combined with the metal to form solid solution; and that these three forms are in mobile equilibrium in some such way as is indicated by the scheme

$$2H + 2xM \rightleftarrows 2MxH \rightleftarrows H_2 + 2xM. \qquad (1)$$

Since the fact is well established that the formation of solid solutions between two metals brings about a great increase in the electrical resistance beyond the value which would result from simple mixture, it is natural to attribute the permanent increase of resistance in hydrogen alloys such as palladium-hydrogen to this combination; and if the supplementary conduction is attributed to the atomic hydrogen, it is evident that, upon the conception just outlined, this conduction must vary with the cathodic current density during electrolysis, as has been found to be the case, and must persist after the interruption of electrolysis until the equilibria of equation (1) have become established.*

If the foregoing explanation be essentially correct, the conduction in question is that of a gas confined within the cavities of the metal. It is accordingly not to be expected that it will conform to Ohm's law, but rather that the resistance observed will depend upon the intensity of the current employed in its measurement, or in other words, upon the applied e. m. f.

The experiments about to be described were, therefore, undertaken in order to test this prediction in the case of palladium-hydrogen since the earlier observations, having been made by null methods, gave only the resistance for "zero current."

Experiments.—The cathode investigated consisted of a wire of commercially pure palladium, 0.05 mm. in diameter, and approximately 110 mm. in length. The cell and thermostat were those which have been described elsewhere,[3] as were also the manner of attaching and supporting the cathode wire, save that arrangements for observing changes of length

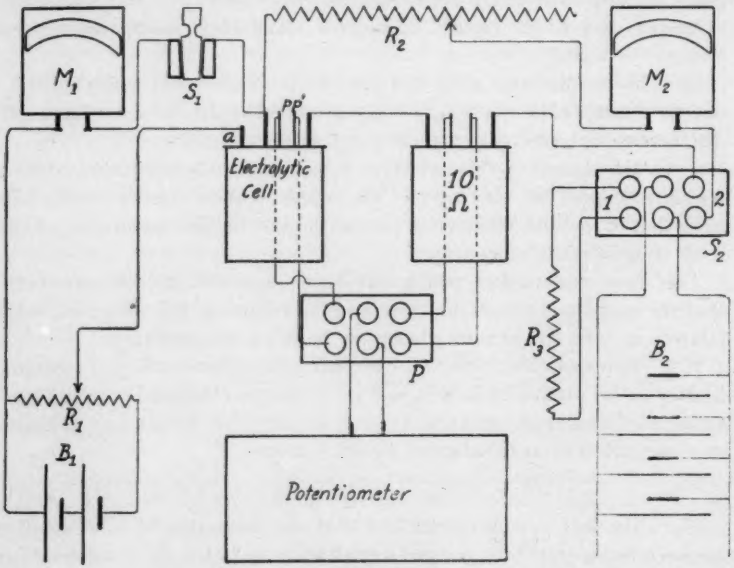

FIG. 1

Electrical connections

were dispensed with. The electrolyte was 2-*n* sulphuric acid, which was caused to circulate during the experiment, as heretofore. The temperature was maintained throughout at 25.00 ± 0.02° C.

The electrical connections are represented diagrammatically in figure 1, where the electrolytic circuit is shown at the left (subscripts "1"); and the resistance-measuring circuit at the right (subscripts "2").

An experiment was conducted as follows: The switch S_2 being in position 1, so that the battery B_2 was short-circuited through R_3 and the resistance-measuring circuit was open, the electrolytic circuit was closed by means of the plug switch S_1, and was regulated with the variable resistance R_1 until the millammeter M_1 showed the current corresponding to the desired cathodic current density. Electrolysis was then continued,

with occasional regulation of the current, until the cathode wire had attained saturation, the time required being calculable from the data previously obtained.

After the electrolytic current had been interrupted by withdrawing the plug S_1 the resistance-measuring circuit was closed by throwing the switch S_2 into position 2. The current, derived from the battery B_2, which consisted of four large storage cells in parallel, was now regulated by means of the resistance box R_2 until the millammeter M_2 gave the reading sought. This was from 2 to 4 milliamperes, these values being selected upon the consideration that for the sake of constancy the current should be as small as the precision of the potentiometer would permit.

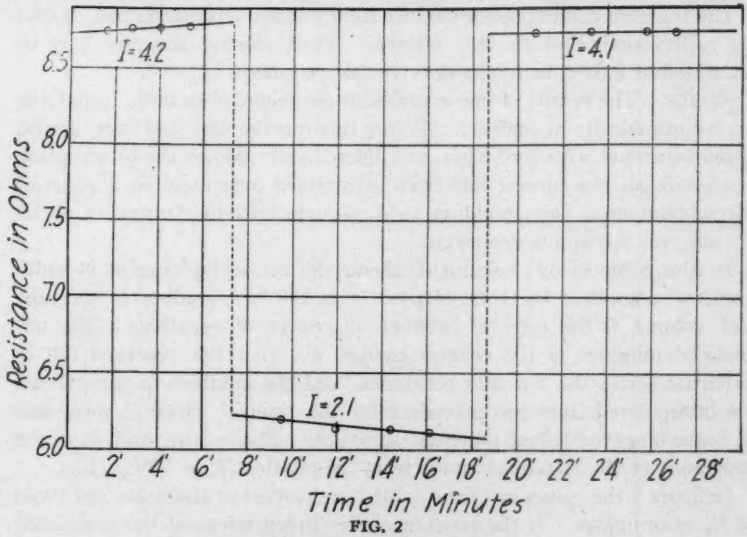

FIG. 2

Dependence of resistance on current

By means of the Pohl commutator P the potentiometer was now connected alternately to the potential leads, p and p', coming from the ends of the cathode wire, and to those of the ten-ohm comparison resistance, readings of the fall of potential across the two resistances being taken several times in rapid succession, while the time was in each case noted, in order that the value for the ten-ohm might be calculated by interpolation for the exact moment at which that for the cathode wire was observed. This made it possible to eliminate the error which would otherwise have resulted from the gradual drift in the resistance of the cathode, and hence in the measuring current.

A complete experiment consisted of three such series of observations as that which has just been described, obtained at intervals as short as possible. The first and last were taken with a measuring current of ap-

proximately 4 milliamperes, and the intermediate one with a current of half this intensity.

The potentiometer employed was a low-resistance "Type K" instrument by Leeds and Northrup, with which was used a suspended coil galvanometer by the same makers. The latter was adjusted by means of a shunt until its vibrations were aperiodic, and had under these conditions a sensibility more than adequate. Care was taken before the beginning of an experiment to bring the potentiometer battery to such constancy of e. m. f. that errors from this source were negligible, and this constancy was checked at least once in the course of each series of observations by comparisons with a set of standard cells.

The ten-ohm comparison resistance used was not a precision coil, so that the resistances found are only relative. Their relative accuracy may be estimated at 0.02% in the least favorable instances.

Results.—The results of one experiment are recorded in table I, and displayed graphically in figure 2. Before this run the wire had been several times saturated with hydrogen, and immediately before the interruption of electrolysis the current had been maintained over night at a value of 2.3 milliamperes, corresponding to a cathode current density of about 1.4 amperes per square decimeter.

In the table below, column 1 shows the measuring current in milliamperes; column 2 the time elapsed from the first reading in seconds; and column 3 the interval between successive observations. The unenclosed numbers in the column headed E_{10} give the observed fall of potential across the ten-ohm resistance, and the numbers in parentheses are interpolated from the preceding for the time at which E_x was read. E_x is the observed fall of potential across the cathode wire; and R_x is the resistance of the latter calculated from the relation $R_x = 10 \cdot E_x/(E_{10})$.

In figure 2 the values of t from table I are plotted as abscissae, and those of R_x as ordinates. If the resistance were independent of the measuring current, the values for all three series of the table should lie upon an unbroken curve which is very nearly rectilinear; but it will be seen that the points for the intermediate series, taken with a measuring current only half as great as that used in the two end series, fall far out of line. A diminution of current of 50% has produced a diminution of resistance of some 30%.

This result was confirmed by that of an entirely similar experiment in which the changes of current and of resistance were, respectively, fifty and forty-two per cent; and finally by that of an experiment in which the electrolyte was withdrawn from the cell, before the resistance of the wire was observed, and in which the corresponding decrements were fifty and twenty-six per cent. It should be pointed out that only qualitative agreement between the several experiments was to be expected, since the magnitude of the effect is dependent both upon the quantity and

TABLE 1

i	t	Δt	E_{10}	E_x	R_x
4.2	0		0.039556		
		98			
	98		(0.039561)	0.034600	8.7459
		34			
	132		0.039564		
		33			
	165		(0.039561)	0.034663	8.7619
		33			
	198		0.039558		
		43			
	241		(0.039558)	0.034695	8.7656
		41			
	282		0.039559		
		38			
	320		(0.039557)	0.034733	8.7805
		38			
	358		0.039555		
2.1	467		0.020035		
		104			
	571		(0.020217)	0.012521	6.1933
		61			
	632		0.020338		
		87			
	719		(0.020338)	0.012488	6.1402
		35			
	754		0.020338		
		110			
	864		(0.020338)	0.012479	6.1358
		43			
	907		0.020338		
		61			
	968		(0.020338)	0.012435	6.1142
		30			
	998		0.020338		
4.1	1157		0.039604		
		91			
	1248		(0.039540)	0.034522	8.7334
		59			
	1307		0.039563		
		88			
	1395		(0.039564)	0.034583	8.7410
		55			
	1450		0.039564		
		93			
	1543		(0.039564)	0.034547	8.7319
		30			
	1573		0.039564		
		48			
	1621		(0.039564)	0.034572	8.7382
		29			
	1650		0.039564		

upon the condition of the occluded hydrogen at the time of observation.

That the results were not materially affected by fluctuations of the measuring current is probably sufficiently attested by the regularity of the observations in each series. The precaution was nevertheless taken of substituting for the palladium wire a nearly equivalent manganin resistance, and conducting with this a similar series of measurements. The resistances found were in this instance constant to the fourth significant figure, showing that with the battery employed, which had a capacity of 240 ampere-hours, and supplied only 4 milliamperes or less, at 2 volts, the variations were wholly negligible.

Conclusion.—The fact seems to be established by the foregoing experiments that the temporary supplementary conduction exhibited by metals during cathodic occlusion of hydrogen, and for some time thereafter, is not of ordinary metallic character. Strictly regarded, this has been shown only in the case of palladium-hydrogen; but the great similarity previously shown[3] to exist in the comportment of palladium, of tantalum and of iron toward hydrogen, and of palladium toward oxygen, makes it probable that the supplementary conduction is of the same character in all cases.

The outcome of the experiments is accordingly in conformity with the prediction based upon the first of the three explanations of the conduction which were enumerated above, and lends support to this conception. Upon either of the other two hypotheses the departure from Ohm's law would be difficult to understand.

Obviously, it is to be expected that with measuring currents much higher than those here employed the supplementary conduction would approach a limiting value, owing to the inability of ordinary diffusion to maintain the concentration of hydrogen atoms in the regions from which these are driven by the current. Above this limit the dependence of resistance on current would not be observed. Unfortunately the likelihood of being able to test this further prediction experimentally seems small; for it may be seen from the magnitude of the change of resistance in the range studied that its disappearance can be looked for only at very large values of the measuring current; and with such currents the heating effects would render doubtful any results which might be obtained.

In concluding, acknowledgment should be made of the excellent assistance rendered in these experiments by Mr. Robert F. Mehl.

[2] The assumption of the existence of molecular hydrogen within the metal seems to be made necessary by certain facts which are not here considered, and the present considerations will not be affected if the quantity of the molecular form is taken to be extremely small, or even zero.

[1] Smith, D. P., and Martin, F. H., *J. Amer. Chem. Soc.*, **38**, 1916 (2577); Harding, E. A., and Smith, D. P., *Ibid.*, **40**, 1918 (1508). Summarized in *Trans. Amer. Electrochem. Soc.*, **34**, 1918 (177).

[2] Newbery, E., *J. Amer. Chem. Soc.*, **41**, 1919 (1887).

[3] Harding and Smith, *loc. cit. supra.*

THE VASCULAR ANATOMY OF NORMAL AND VARIANT SEEDLINGS OF PHASEOLUS VULGARIS

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The investigations here summarized comprise a comparative and biometric study of the gross vascular anatomy of normal and variant seedlings of *Phaseolus vulgaris*.

Three morphological types have been considered, (*a*) the normal or *dimerous* seedling with two cotyledons and two primordial leaves, (*b*) the *trimerous* seedling with three cotyledons and three primordial leaves, and (*c*) the *hemitrimerous* seedling in which there are three cotyledons and two primordial leaves.

In normal seedlings, the vascular system of the root is typically tetrarch (with four protoxylem poles), and gives rise in the base of the hypocotyl to four pairs of double bundles which soon form a circle of eight bundles which continue to the cotyledonary node. At this point there is a complex vascular anastomosis. From it two strands are given off to each cotyledon. The remainder of the vascular tissue is reorganized into six strands, each of which typically soon divides into two, the twelve bundles thus formed comprising the vascular system of the epicotyl.

The trimerous seedlings typically possess six root poles instead of four, twelve bundles in the hypocotyl instead of eight, and nine primary epicotyledonary bundles instead of six. The nine primary epicotyledonary bundles do not all divide, however, so that the number of bundles in the central region of the epicotyl is variable ranging in general from fourteen to eighteen.

In both classes of seedlings, but more frequently in the normal type, additional or intercalary bundles appear in the hypocotyl, either *de novo* or as a result of division of the primary strands.

Four main groups of problems as to the vascular topography of these seedling types have been considered biometrically: First, the number of bundles at different levels in the seedling; second, the variability in bundle number; third, the differentiation in internal structure of seedlings which are externally dimerous, trimerous and hemitrimerous; and fourth, the interrelationship of bundle number in different regions of the seedling.

The following table of constants[1] summarizes the facts for number and variability of vascular bundles in various regions of the seedling and in the three types of seedlings.[2]

The constants in this table, and the frequency distributions from which the constants were computed, lead to the following conclusions.

	DIMEROUS SEEDLINGS			TRIMEROUS SEEDLINGS			HEMITRIMEROUS SEEDLINGS		
	Mean	S. D.	C. V.	Mean	S. D.	C. V.	Mean	S. D.	C. V.
Root poles									
Minimum	4.01	0.081	2.03	5.02	0.654	13.02			
Maximum	4.13	0.338	8.18	5.16	0.729	14.12			
Mean	4.05	0.171	4.19	5.09	0.707	13.87			
Primary double bundles									
Minimum	4.02	0.140	3.48	5.81	0.288	4.86	5.21	0.608	10.59
Maximum	4.52	0.666	14.74	5.98	0.581	10.01	5.74	0.750	14.07
Mean	4.19	0.411	9.66	5.91	0.405	6.87	5.49	0.676	12.37
Intercalary bundles									
Minimum	0.07	0.261	105.79	0.09	0.292	156.62	0.28	0.449	115.47
Maximum	0.83	1.024	355.48	0.29	0.686	381.67	0.53	1.148	214.68
Mean	0.49	0.687	182.70	0.19	0.491	274.92	0.44	0.737	163.82
Mid-region of hypocotyl									
Minimum	8.11	0.409	5.04	11.99	0.532	4.42	11.36	1.169	9.94
Maximum	10.62	1.645	17.34	12.29	1.283	10.44	12.32	1.524	12.87
Mean	9.23	1.193	12.67	12.16	0.883	7.24	11.94	1.307	10.96
Mid-region of epicotyl									
Minimum	12.11	0.406	3.35	14.89	1.152	7.74	12.93	1.245	9.07
Maximum	12.36	0.757	6.13	16.10	1.750	10.87	14.84	1.778	12.53
Mean	12.22	0.586	4.79	15.47	1.383	8.92	13.83	1.560	11.29

The modal number of primary double bundles in the region of transition from root to stem structure at the base of the hypocotyl is four in the dimerous and six in the trimerous and hemitrimerous seedling. In the normal seedlings more than four bundles may occur, but in no case have fewer than this number been observed. In the trimerous seedling variation both above and below the mode is found, the numbers ranging from four to eight. On the average the number is from 1.38 to 1.89 bundles higher (or from 30.5 to 47.0% higher) in the trimerous than in the dimerous seedlings.

Intercalary bundles, which are rather uncommon in seedling anatomy in general, occur in from 11 to 46% of the normal seedlings, whereas they are found in only 9 to 29% of the trimerous and in 28 to 43% of hemitrimerous seedlings. The average number of intercalary bundles is also generally higher in the dimerous plantlets.

Considering the total bundle number at the base of the hypocotyl (primary bundles plus intercalary bundles) the trimerous and hemitrimerous seedlings have from 0.77 to 1.91 bundles, or from 14.4 to 46.7%, more than the dimerous seedlings. The differentiation of the dimerous

and trimerous seedlings is conspicuously shown by the frequency distributions of two of the lines shown in diagram 1.

In passing upward from the base of the hypocotyl, each primary bundle pair normally divides into two so that in the central region of the hypocotyl the bundle number is normally twice the number of primary double bundles at the base, plus the intercalary bundles. In many cases the number is somewhat in excess of this, however, showing either that new (intercalary) bundles have appeared or that some of the bundles have become subdivided.

The modal number of bundles in the mid-region of the hypocotyl is eight or ten in dimerous plantlets; in trimerous and hemitrimerous plantlets

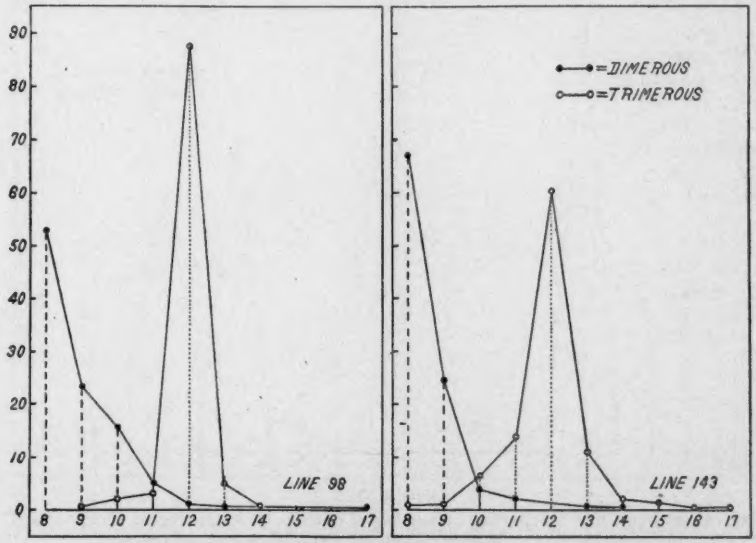

DIAGRAM 1

Percentage frequency distributions of total bundles (primary double bundles counted as two) at the base of the hypocotyl in dimerous and trimerous seedlings of two lines. Abscissae represent bundle numbers, ordinates represent percentage frequencies.

it is twelve. On the average the number is from 1.7 to 3.8 bundles higher (or from 15.7 to 47.9% higher) in the trimerous than in the dimerous seedlings. The differentiation of the two classes of seedlings in their vascular anatomy at the level is clearly shown in diagram 2.

The bundles in the mid-region of the epicotyl show in dimerous plantlets a modal number of twelve, whereas in trimerous seedlings it is fifteen. On the average there are from 2.8 to 3.7, or from 23.0 to 30.2%, more bundles in the epicotyl of the trimerous than in the dimerous seedling.

The form of the frequency distributions for two of the lines is shown in diagram 3. The epicotyl of the hemitrimerous is in essentials of anatomy identical with that of the dimerous seedling.

Not only are there marked differences in the actual number of bundles, but the variability of bundle number changes from region to region of the seedling, and differs in the three seedling types. Whether judged by range, standard deviation or coefficient of variation, the variability of bundle number in the central region of hypocotyl tends to be distinctly higher in the dimerous than in the trimerous plantlets; but in the epicotyl just the reverse is true, the variability of the trimerous plantlets exceeding that of the dimerous. These differences are conspicuous in diagrams 2

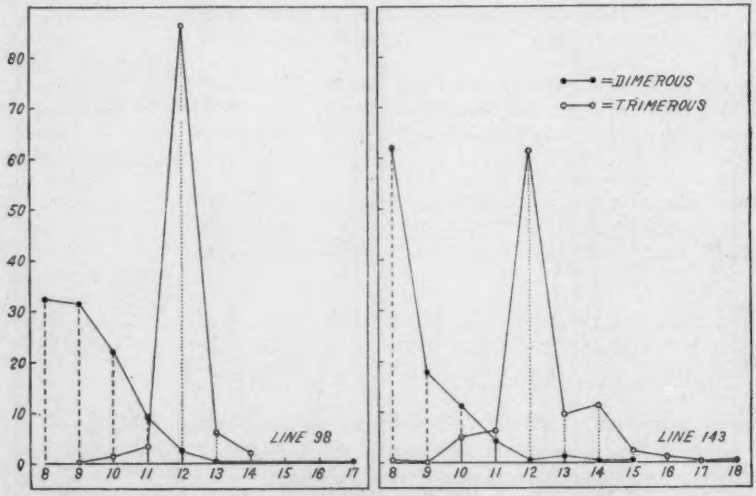

DIAGRAM 2

Percentage frequency distribution of number of bundles in central region of hypocotyl in dimerous and trimerous seedlings. Abscissae represent bundle numbers, ordinates represent percentage frequencies.

and 3. In the first case it is the dimerous plantlets, in the second case it is the trimerous ones which show the greater variability. Apparently this is due to differences in the number of intercalary bundles in the hypocotyl, and to the extent of division of the bundles in the epicotyl, of the two types of seedlings.

The coefficients of correlation between various bundle systems also differ widely. In both trimerous and dimerous seedlings there is a negative correlation between the number of primary double bundles and the number of intercalary bundles at the base of the hypocotyl. Thus the number of intercalary bundles is smaller in seedlings with larger numbers of primary double bundles and vice versa. This result for seedlings of the

same (external) morphological type is in agreement with those obtained by a comparison of seedlings which are externally dimerous and trimerous, since the latter frequently have a larger number of primary double bundles but a smaller number of intercalary bundles than the former. In both types of seedlings variation in the number of intercalary bundles is the primary factor in determining variation in the total number of bundles at the base of the hypocotyl.

Turning to the problem of the interrelationship of bundle number at different levels in the seedling we find that there is a substantial correla-

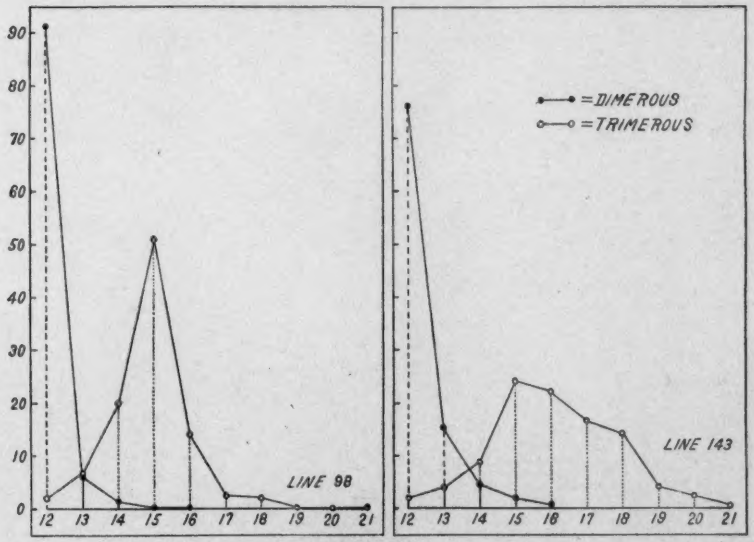

DIAGRAM 3

Percentage frequency distributions of total bundle number in the central region of the epicotyl of dimerous and trimerous seedlings of two lines. Abscissae represent bundle numbers, ordinates represent percentage frequencies.

tion between the numbers of the three classes of bundles—primary double bundles, intercalary bundles, and total bundles—at the base of the hypocotyl and the number of bundles in the central region of the hypocotyl. In the normal seedlings the coefficients average +0.509 for number of primary double bundles and number of hypocotyledonary bundles, +0.629 for intercalary bundles and hypocotyledonary bundles, and +0.813 for total bundles and hypocotyledonary bundles. In the trimerous plants these correlations average +0.381, +0.238 and +0.598, respectively. The correlations for normal plantlets are practically without exception higher than those for abnormal seedlings.

The correlations between the number of bundles in the hypocotyl (both basal region and central region) on the one hand and the number of

bundles in the central region of the epicotyl on the other differ conspicuously from those found between the numbers of bundles at the two levels in the hypocotyl itself, in that the coefficients are extremely slight. They are positive in some series, but negative in others.

The regression straight lines and the empirical means for number of bundles in the hypocotyl (lower line) and epicotyl (upper line) associated with various numbers of primary double bundles at the base of the hypocotyl in two of the lines is shown in diagram 4. The irregularity of the means is at least in part due to the fact that the frequencies are largely concentrated in the two classes of 4 and 5 primary double bundles. The

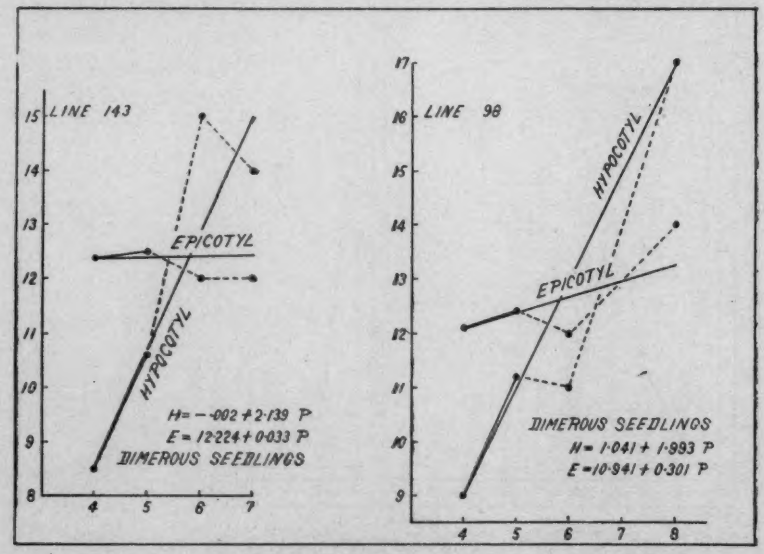

DIAGRAM 4

Regression of number of bundles in central regions of hypocotyl and of epicotyl on number of primary double bundles at base of hypocotyl. Abscissae represent primary double bundles, ordinates represent mean number of bundles in hypocotyl and epicotyl.

slope of the line representing change in hypocotyledonary bundles associated with variation in number of basal bundles is steep, showing a rather close dependence; but the line showing the change in epicotyledonary bundles associated with the same variations in basal bundles is very slight, showing the laxness of the interdependence of bundle number in these two regions.

On the basis of the data available it is impossible to assert that there is any relationship at all between bundle number above the cotyledons and bundle number below them. These results indicate that there is a *complete reorganization of the vascular system at the cotyledonary node.*

It will be evident from the foregoing outline that the vascular structures of the seedling are not constant but are highly variable, even within genetically very homogenous material. It is quite possible, therefore, that anatomical investigations based on but a few sections for each species might lead to erroneous results. Seedlings differing in external form are differentiated in their internal anatomy. Such differentiation is evident not only in mean number of bundles but in the degree of variability in bundle number. Thus, in normal seedlings the variability is higher in the hypocotyl than in the epicotyl, whereas in seedlings with three cotyledons and three primordial leaves just the reverse is true. The external form and the internal structure of the seedling are highly but not perfectly correlated. Finally in both normal and variant seedlings, the number of vascular elements of the several regions of the seedling are correlated in very different degrees; the correlation between some is high; between others it is practically wanting.

Papers to appear in the *American Journal of Botany* may be consulted for details.

[1] The values given in each case are the maximum and minimum constants for the lines investigated. For the trimerous and dimerous seedlings all the averages are based on five lines. For the hemitrimerous seedlings the averages for primary double bundles and intercalary bundles are based on five lines while for the mid-region of hypocotyl and the mid-region of epicotyl they are based on six lines. Data for number of root poles are available for only three lines.

[2] Because of the extreme rarity of hemitrimerous seedlings it is not feasible to discuss variability of bundle number in this group.

THE PRESENT STATUS OF THE LONG-CONTINUED PEDIGREE CULTURE OF PARAMECIUM AURELIA AT YALE UNIVERSITY

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As a matter of record it seems advisable to bring up to date and summarize the chief results derived from the writer's main pedigree culture of Paramecium aurelia.

This culture, designated Culture I, was started on May 1, 1907, by the isolation of a "wild" individual which was found in a laboratory aquarium.[1] The original specimen was placed in about five drops of culture fluid on a glass slide having a central ground concavity, and when this animal had produced four individuals, each of these was isolated on a separate slide to form the four lines of the culture. The four lines have not been kept distinct from one another throughout the work, but have been replenished by cells from one of the sister lines when, through accident or otherwise, one or another of the lines has become extinct.

The culture has been maintained by the isolation of a specimen from each of these lines practically every day, with the exception noted below. The number of divisions in each line has been recorded at the time of isolation and the average rate of these four lines has again been averaged for varying numbers of days (5, 10, or 30 days) as the exigencies of the different experiments demanded. These data have afforded the graphs of the division rate. Permanent preparations have been preserved from time to time for the study of the cytological changes during the life history. During the first eight months of the work the culture medium consisted of infusions of hay and fresh grass, but from February, 1908, to the present time various materials collected from ponds, swamps, etc., have been employed. The infusions were thoroughly boiled to prevent the contamination of the pure culture with foreign strains of Paramecium. In short, the cells of the four lines of the culture to-day are direct lineal descendants by division of the single animal isolated in 1907.

The object of starting the culture was to determine whether Paramecium can reproduce by division indefinitely without recourse to conjugation. Throughout the work the possibility of conjugation in the four lines of the culture has been precluded by the almost daily isolation of the products of division. Accordingly its continued life and health has long since justified the conclusion that conjugation, involving syncaryon formation, is not, as previously generally maintained, a sine qua non for the continued life of Paramecium, in particular, and, presumably, of Infusoria in general. At the completion of the

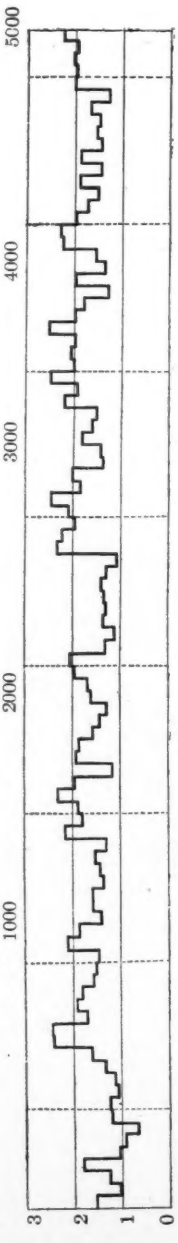

FIG. 1

Graph showing the rate of reproduction of the pedigree race (I) of Paramecium aurelia during the first eight years of culture. The ordinates represent the average daily rate of division of the four lines of the culture, again averaged for each month. The vertical broken lines indicate the limits of the calendar years. The figures 1000, 2000, etc., represent generations and are placed above the periods in which they were attained.

culture's first five years of life, during which over 3029 generations were attained, the writer stated that "the organisms of the present generation are in as normal morphological and physiological condition as the original 'wild' individual isolated to initiate the culture. This study has indicated that, under favorable environmental conditions, the protoplasm of the cell originally isolated possessed (at least) the potentiality to produce similar cells to the number represented by 2 raised to the 3,029th power, or a volume of protoplasm not less than 10^{1000} times the volume of the Earth. I believe this result indicates beyond question that the protoplasm of a single cell may be self-sufficient to reproduce itself indefinitely, under favorable environmental conditions, without recourse to conjugation....."

As a matter of fact organisms taken from this culture of Paramecium have shown but little tendency to conjugate. From time to time experiments to induce conjugation have been carried out in mass cultures started from the pedigree lines. The first successful experiment occurred in December, 1913, at about the 4100th generation.[2] The next epidemic of conjugation in mass culture occurred June, 1920.

Careful studies of the rate of division of sub-lines derived from the main lines and bred under the most constant environmental conditions revealed the fact that there are inherent, normal, minor, periodic rises and falls of the fission rate due to some unknown factor in cell phenomena. These were termed Rhythms.[3] In a search for the underlying factors of rhythms a complicated internal nuclear reorganization process was discovered and named Endomixis.[4] This process involves the periodic formation of a complete new nuclear apparatus by a definite sequence of normal morphological changes which simulate those occurring in conjugation. Endomixis, in essence, consists of a gradual disintegration and absorption of the macronucleus in the cytoplasm. Simultaneously a multiplication of the micronuclei is in progress. Certain of the resulting micronuclei degenerate while the remaining one or two form the new macronuclear and micronuclear apparatus of the cell. This results in the

YEAR	GENERATIONS	DAILY AVERAGE DIVISION RATE
1	452	1.24
2	690	1.89
3	613	1.68
4	612	1.67
5	662	1.81
6	692	1.89
7	671	1.84
8	679	1.86
Average for 8 yrs.	634	1.74

reorganization of the cell (endomixis) without the coöperation of two animals involving syncaryon formation (amphimixis) as in conjugation.

After endomixis was worked out, it seemed unnecessary to continue longer the main pedigreed culture and accordingly on May 1, 1915, at the 5071st generation, the experiment was *formally* considered as closed.

The record of divisions for each year of the life of the culture to May 1, 1915, may be tabulated as shown in the preceding table.

Thus for eight years the culture averaged about fifty generations per month. However, at the formal termination of the experiments in 1915, I was reluctant to discard the race and was tempted to keep it under control but without such exacting daily observation and recording of the daily division rate. In this manner it has been maintained up to the present (December, 1920). But, from time to time, thirty-day tests have been made of the vitality of the race under the former rigid culture conditions, and in each case the same general average division rate has been revealed as during the first eight years of its life. For example, during December, 1915, 52 generations; during December, 1917, 56 generations; and during November, 1920, 54 generations were attained. On the basis of such tests it is fair to make the exceedingly conservative estimate of 600 generations attained each year since May 1, 1915. This would give, in round numbers, 8400 generations attained by the culture during the $13^1/_2$ years of its life to date.

Thus the conclusion is still justified that conjugation is not a necessary phenomenon in the life history of Paramecium aurelia under favorable environmental conditions. But there is an internal reorganization process (endomixis) which occurs periodically. Whether endomixis is a necessary factor for the continuance of the race is another question—a new question which has been raised by these studies, and is now under investigation.[5]

[1] Woodruff, L. L., "The life cycle of Paramecium when subjected to a varied environment," *Amer. Naturalist*, **42**, 1908. "Two thousand generation of Paramecium," *Archiv f. Protistenkunde*, **21**, 1911.

[2] Woodruff, L. L., "So-called conjugating a non-conjugating races of Paramecium," *J. Exper. Zool.*, **16**, 1914.

[3] Woodruff, L. L. and Baitsell, G. A., "Rhythms in the reproductive activity of Infusoria," *J. Exper. Zool.*, **11**, 1911; "The temperature coefficient of the rate of reproduction of Paramecium aurelia," *Amer. J. Physiol.*, **29**, 1911.

[4] Woodruff, L. L., and Erdmann, R., "A normal periodic reorganization process without cell fusion in Paramecium," *J. Exper. Zool.*, **17**, 1914.

[5] Woodruff, L. L., "The problem of rejuvenescence in protozoa," *Biochem. Bull.*, **4**, 1915; "The influence of general environmental conditions on the periodicity of endomixis in Paramecium aurelia," *Biol. Bull.*, **33**, 1917.